

# **Wireless Spectrum The Path Ahead**

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# Agenda

What is different about LTE?

Complexities that impact System Performance and User Throughput

Mobile Device challenges and the impact of Spectrum Band Planning

LTE Advanced

Considerations for future Spectrum Allocations

# LTE – The Technology of the Future

- **4G Technology**

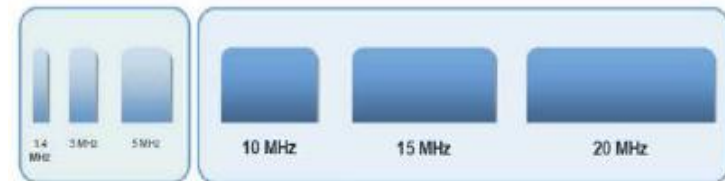
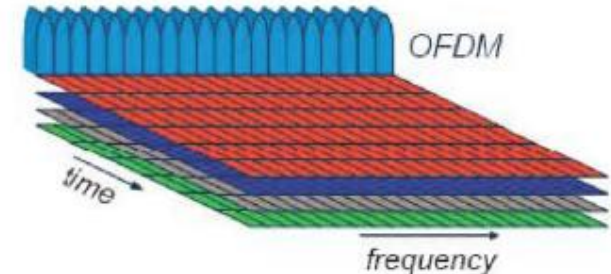
- LTE as defined by 3GPP will be the prevalent future wireless broadband technology
- Downlink is based on OFDMA and uplink is “single carrier” FDMA
- Allows higher spectral efficiency (bits/Hz)

- **Scalable**

- Supports channel bandwidths from 1.4–20 MHz; current focus is on 10 MHz channels
- Channel bandwidths require 2 x XX spectrum allocation

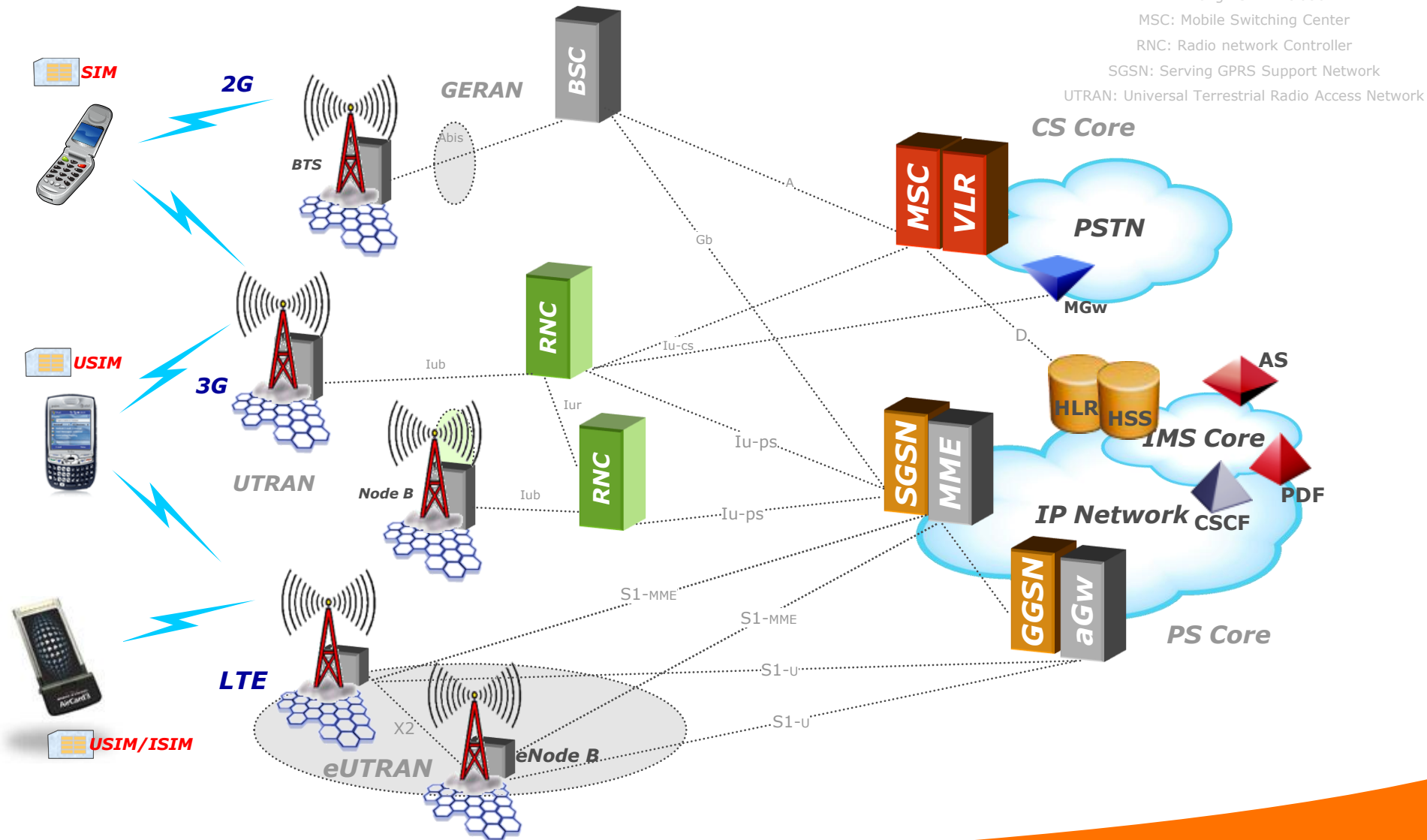
- **Universal Adoption**

- Endorsed as the migration path to future broadband wireless service by almost all wireless carriers worldwide plus Public Safety in the US
- Supports both FDD and TDD
- Clearwire is the sole exception in the US with WiMAX deployed but has expressed a preference for future migration to LTE



# 3GPP Evolution of Wireless Networks

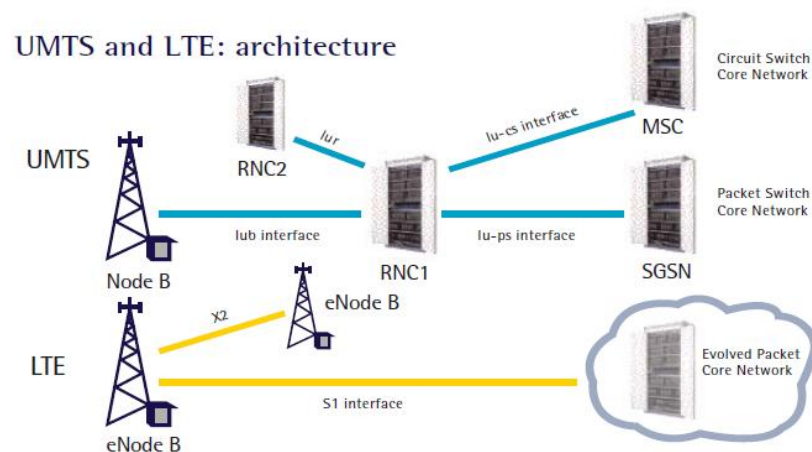
BSC: Base Station Controller  
 BTS: Base Transceiver Station  
 HLR: Home Location Register  
 GERAN: GSM EDGE Radio Access Network  
 GGSN: Gateway GPRS Support Network  
 LTE: Long Term Evolution  
 MSC: Mobile Switching Center  
 RNC: Radio network Controller  
 SGSN: Serving GPRS Support Network  
 UTRAN: Universal Terrestrial Radio Access Network



# How Does LTE Improve on UMTS?

- **Enhanced Air Interface** allows support of wider bandwidths (10 MHz, 15 MHz, 20 MHz)
- **Higher Data Rates** which will continue to be enhanced with LTE Advanced
- **Reduced Latency:** Larger pooling and a flat architecture promotes more efficient utilization, lower queuing delays, and drives higher spectral efficiency
- **High Spectral Efficiency:** Two times that of HSPA 3.6
- **All IP Environment:** Flatter (fewer levels) core architecture

UMTS does not scale as well above 5 MHz bandwidths due to processing requirements in the hardware



*LTE gives operators the benefits of evolution to a simplified, all-IP network architecture.*

# **SYSTEM PERFORMANCE AND USER THROUGH PUT**

# Factors in System Performance (1/2)

Received signal power is a space, frequency, and time varying quantity

Radio performance analysis is statistical in nature, and thus, it is hard to identify a specific value that is representative for all conditions

## Range/Coverage are dependent on:

- **Frequency:** Frequencies lower than 3GHz are best suited for mobility
- **Transmit power:** Higher power supports coverage-limited operation, but power control is typically required for interference-limited operation (i.e. capacity limited)
- **Antenna heights and gain:** Zoning and other considerations play a major factor in base station design, whereas space is critical in device implementations. From a device perspective, higher frequencies are preferred since the corresponding wavelengths are shorter and thus, require less space
- **Receiver sensitivity:** Base station receivers are not typically constrained by processing or space requirements. Conversely, device receivers are.
- **Interference:** Inter or other cell interference will limit the achievable capacity if not effectively controlled
- **Modulation and coding:** Link adaptation and Hybrid ARQ (HARQ) processing support higher throughputs under favorable conditions and extend the cell edge under non-favorable conditions
- **Data rate target:** Guaranteed Bit Rate (GBR) and VoIP services are more demanding than “best effort” data services
- **Terrain, obstructions and foliage** (clutter): Network has to be designed to support coverage in all types of radio environments – dense urban, urban, suburban and rural

# Factors in System Performance (2/2)

**Capacity and throughput are dependent on:**

- **Channel bandwidth and number of channels:** higher channel bandwidths and Carrier Aggregation (CA) support higher peak and average throughputs
- **Technologies to be supported and the device types and mix:** Spectral efficiency of 3G devices is dependent upon RX type, where the percentage of each type changes over time.
- **Efficiency of individual technologies served:** Our networks are supporting multiple technologies, so the overall mix impacts the overall efficiency.
- **Traffic type and mix:** Current services include circuit switched voice, text messaging, web browsing, file transfer, and video streaming, while future services include multiple services that require varying levels of QoS
- **Interference characteristics:** Inter or other cell co-channel interference is the dominant interference mechanism
- **Backhaul to cell site:** Significant build-out of backhaul infrastructure is required to support higher HSPA/HSPA+ and LTE throughputs
- **Core network capabilities:** Key sub-systems must be sized appropriately to assure negligible impact on throughputs. In addition, delays need to be kept to acceptable levels to support real-time services such as VoIP and gaming
- **Number and location of sites and users :** Initial deployments may typically have fewer sites and users as compared to mature network.



# Factors in System/User Performance

**End user performance depends on (in addition to the previous)**

- **System peak throughput and capacity:** The user can only experience what the network can deliver
- **Where the user is located in the cell:** Users at the cell-edge will experience lower throughputs,
- **Number of users in the cell (shared resource):** This is a “shared resource” which means that total demand at that site will impact the performance of each user.
- **Traffic characteristics of the user in the cell:** Users with higher QoS requirements typically have priority over best effort data services.
- **Device type and capabilities:** Technology type (i.e. HSPA 3.6 vs 7.2) and the capabilities of the receiver (i.e. receive diversity) will impact the user experience.
- **Local interference:** Depending upon the type of serving cell (macro, micro, pico, femto) and user location (indoor/outdoor), the resulting Signal to Interference plus Noise Ratio (SINR) may vary significantly
- **Mobility Speed:** User experience is typically better for lower mobility conditions than it is for higher mobility conditions primarily due to poorer channel estimation, which leads to more bit errors at the receiver

**Individual Users Rarely See the Peak Theoretical Rate**

# User Performance/Spectral Efficiency Comparisons

## Caveats for performance figures shown on the following page

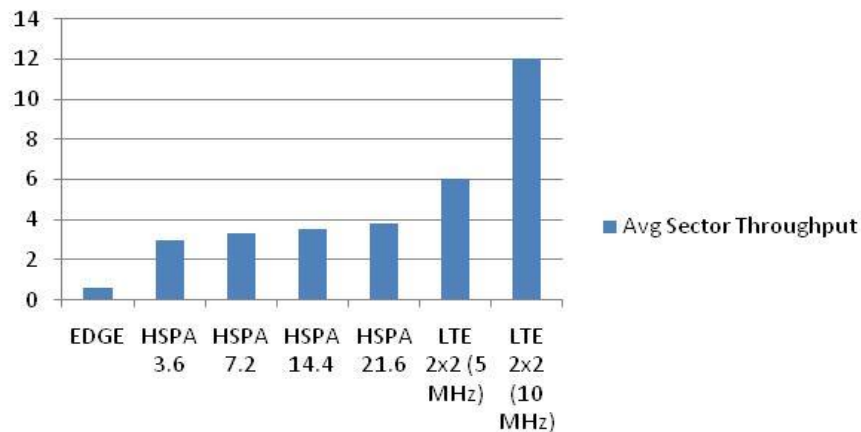
- All performance figures assume that all devices in the network are of a given type/capability
- Mixed device use (real world) will result in lower spectral efficiencies and speeds – cannot achieve full efficiency
- Performance figures assume cell sites deployed on a homogeneous, hexagonal grid. Site issues include
  - Terrain
  - Zoning
  - Land use
- Performance figures assume entire channel is used for best effort data, and thus, a mix of voice, GBR and best effort data traffic will impact the efficiency shown
- Although every effort is made to accurately model all processes some simplifications are made in the simulators upon which these results are based. One can never completely capture all real-world effects

# Technology Evolution

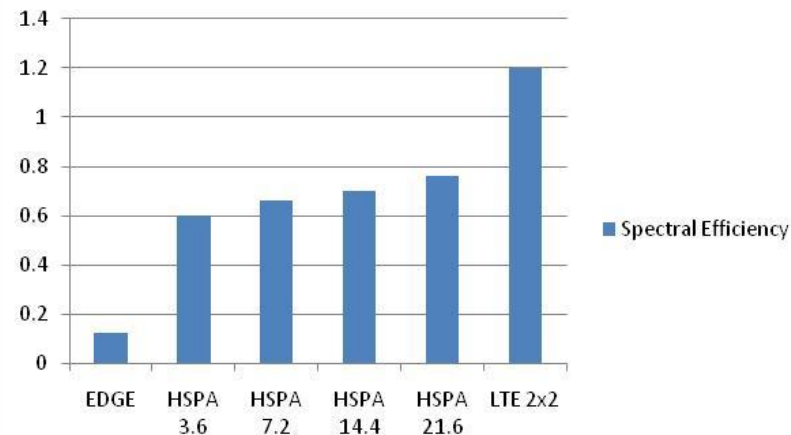
(2 Channel Sizes Shown for LTE, others are at 5 MHz)

Note: these figures are a snapshot in time of simulation results and are subject to change

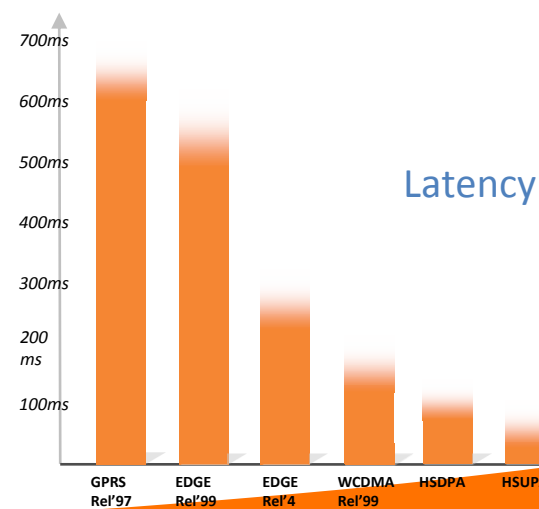
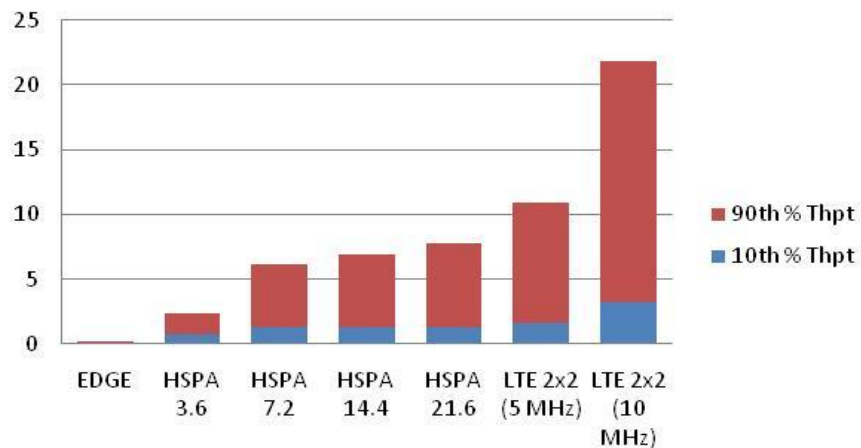
## Avg. Sector Throughput (Mbps)



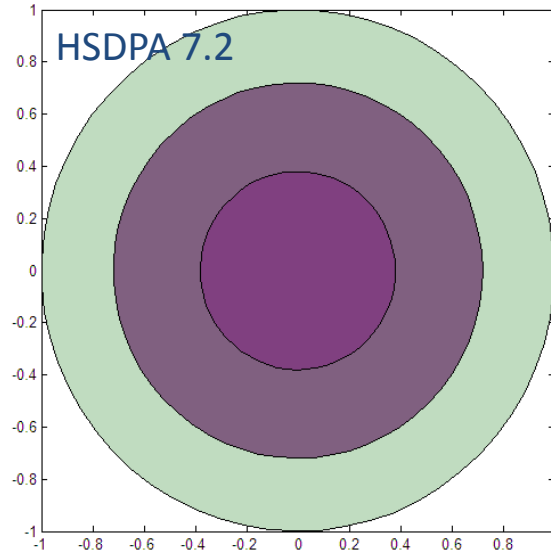
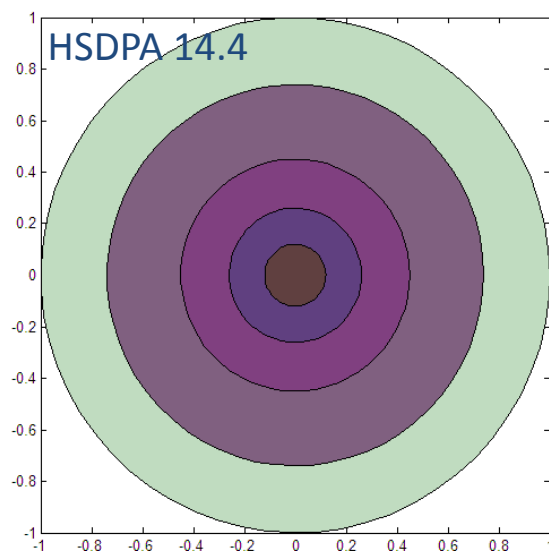
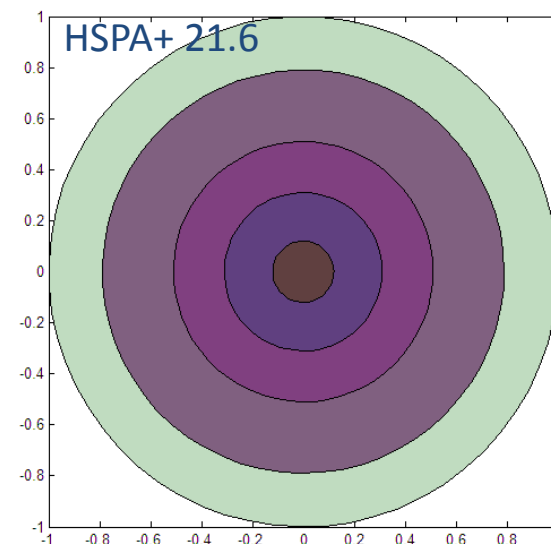
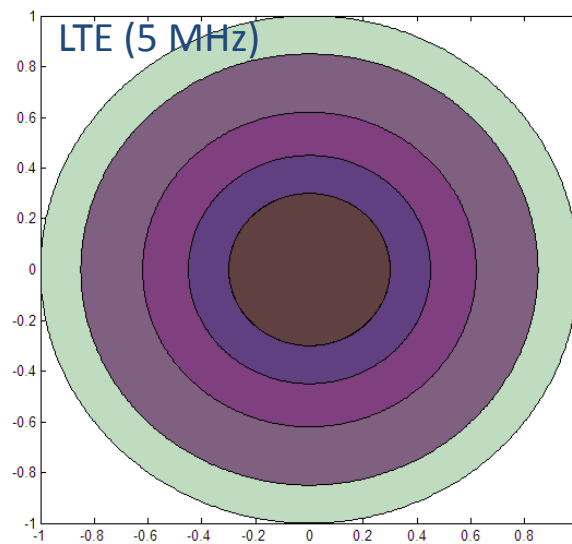
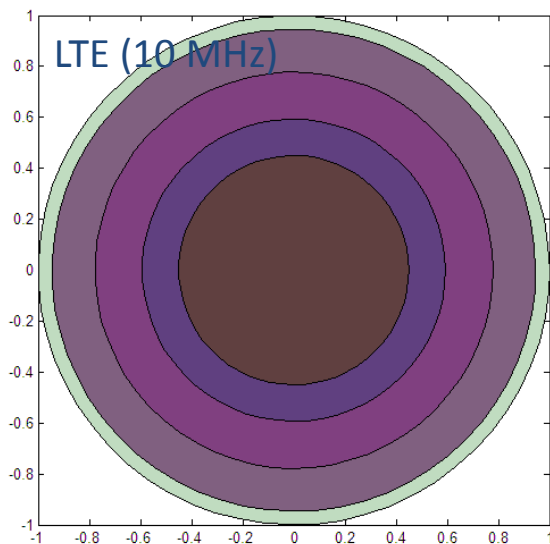
## Spectral Efficiency (bps/Hz)



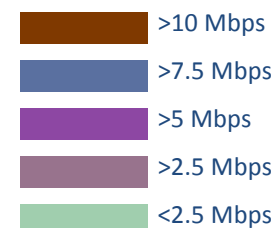
## Single User Speed (Mbps)



# Data Rate Coverage Illustration

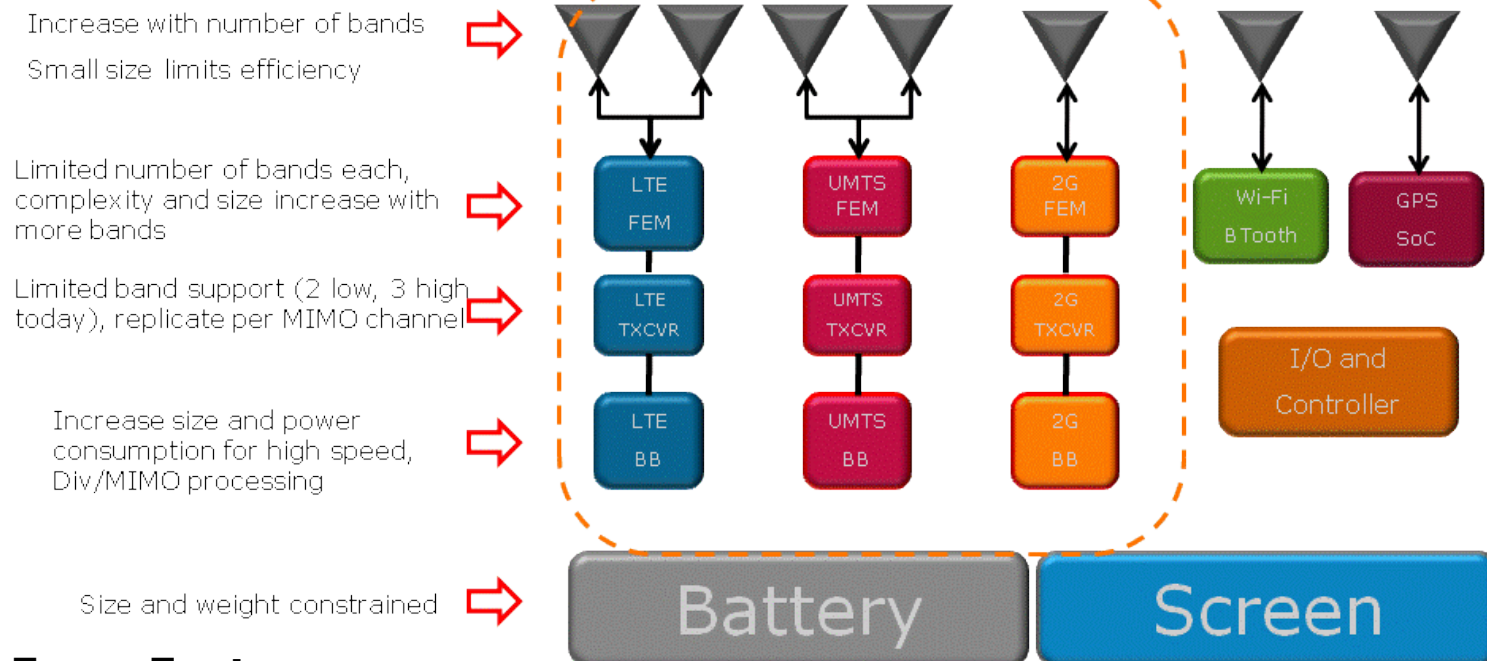


The concentric circles show the % of area within a cell site where the achieved data rate (given a single UE per sector) will be higher than the given threshold



# **MOBILE DEVICES AND SPECTRUM BAND PLANNING**

# Mobile Device Constraints/Challenges



## Form Factor

Space, power and cost constrained; once devices are in the field they are difficult to upgrade

## Front End Module (FEM)

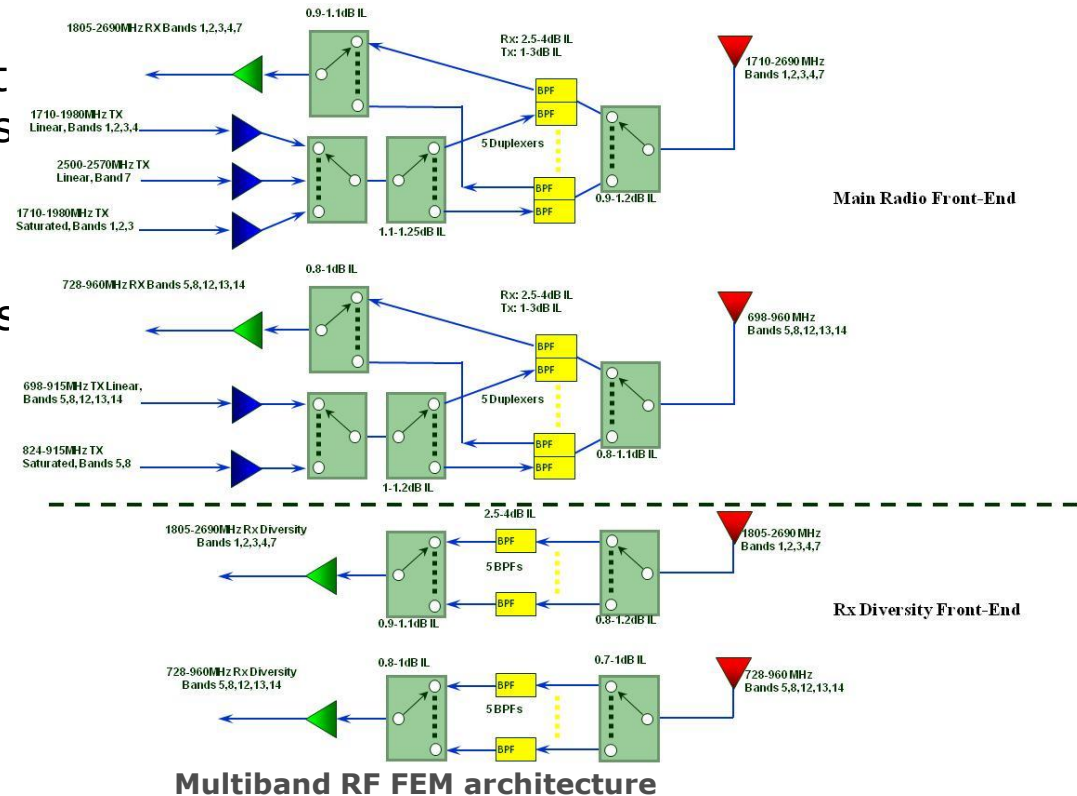
The FEM includes filters, oscillators, mixers and amplifiers, a complex mix of active and passive components that are not always easily integrated. Each additional frequency band increases the number of RF components with associated real estate and cost components

# Device Radio Multiband Architecture

- Demands on components in the RF signal chain of a mobile handset increases with the number of bands and modes

- Devices are limited to # of inputs/outputs and hardware blocks that can be supported in chipset architectures including

- # of front-end duplexer filters, ports on switches, amplifiers
- # of high-performance antennas on the device RF chip(s) + baseband processor chip, additional paths for diversity and/or MIMO



- A decision to support RF bands is a complex process between an operator and their handset vendors as it involves support of legacy and new technologies and bands for international roaming

- FCC band plan strategy impacts the number of bands for future spectrum allocations

# Spectrum Band Plan Impact on Devices

**Additional radios:** 4G phones will support **2** low / **3** high band (3G+4G) radios in 2011. Some chipset manufacturers are developing **4** low / **4** high band (3G+4G) radios but the device availability timeline could be 2015

**Band spanning:** The ability for a single radio to span more than one band, e.g. AWS-1 and AWS-3; Lower 700 MHz B/C; E-SMR and 850 MHz

**Dual mode radio:** The ability for a single radio to support both 3G and 4G within same spectrum band (e.g. 850 MHz) (Some chipsets do not, others do)

**Spectrum aggregation:** The ability for a chipsets support channel logical bonding of two or more spectrum bands. This will be critical for LTE Advanced and higher speeds.



# US Frequency Blocks : Current & Future

NOTE: Bands for international roaming will be additional

Current + Future Low Bands		Current + Future High Bands	
1	850 MHz (Cellular)		1900 MHz (PCS)
2	800 MHz (ESMR)		1700 MHz (AWS1)
3	Lower 700 MHz (A/B/C)		1500 MHz (MSS)
4	Lower 700 MHz (B/C)		2200 MHz (MSS)
5	Upper C 700 MHz		2300 MHz (WCS)
6	Upper D /Public Safety Block		2600 MHz (BRS/EBS)
7	Broadcast Spectrum Block I **		H Block
8	Broadcast Spectrum Block II **		J Block
9			AWS3 Block

\*\* - Assumes a consolidated nationwide band plan encompassing 120 MHz

# Roaming - 3GPP Frequency Bands

Band	Uplink		Downlink		Duplex	Mode
1	1920	1980	2110	2170	130	FDD
2	1850	1910	1930	1990	20	FDD
3	1710	1785	1805	1880	20	FDD
4	1710	1755	2110	2155	355	FDD
5	824	849	869	894	20	FDD
6	830	840	875	885	35	FDD
7	2500	2570	2620	2690	50	FDD
8	880	915	925	960	10	FDD
9	1749.9	1784.9	1844.9	1879.9	60	FDD
10	1710	1770	2110	2170	340	FDD
11	1427.9	1452.9	1475.9	1500.9	23	FDD
12	698	716	728	746	12	FDD
13	777	787	746	756	21	FDD
14	788	798	758	768	20	FDD
15	1900	1920	2600	2620	700	FDD
16	2010	2025	2585	2600	575	FDD
17	704	716	734	746	30	FDD
33	1900	1920	1900	1920	0	TDD
34	2010	2025	2010	2025	0	TDD
35	1850	1910	1850	1910	0	TDD
36	1930	1990	1930	1990	0	TDD
37	1910	1930	1910	1930	0	TDD
38	2570	2620	2570	2620	0	TDD
39	1880	1920	1880	1920	0	TDD
40	2300	2400	2300	2400	0	TDD

- In total there are 25 bands identified as E-UTRA frequency bands and several more bands are being considered in 3GPP for digital dividend allocation in region 1 and in region 3
- Already a complex set of bands that will become more complex over time

# LTE ADVANCED

# LTE-Advanced (1/2)

- **Performance goals**
  - Wider bandwidth - aggregate up to 100 MHz
  - Reduced latency
  - More spectrally efficient
  - Higher peak data rates
- **Carrier aggregation – asymmetric use**
  - Combine carriers to create higher peak speeds and lower latencies
  - Yields trunking gains in user throughput
  - Can combine asymmetrically to use unpaired channels
- **Relays**
  - Extend coverage and fill holes without wired backhaul
  - Ease of temporary network deployment (e.g. event-specific capacity surge, disaster relief)
  - Group mobility (e.g. relay on a train/bus)

# LTE-Advanced (2/2)

- **Heterogeneous networks and enhanced interference coordination**
  - Low power nodes placed throughout a macro-cell to add capacity
  - Coordinated macro and microcell layers for interference mitigation
  - Increased footprint of pico/femto cells permits increased macro off-load
- **Improved MIMO (Multiple Inputs-Multiple Outputs)** processing for higher speeds and better efficiency
  - Higher order MIMO – primarily useful for fixed applications
  - UL MIMO – improved efficiency and speed from device to the network
  - Multi-User MIMO – improved efficiency
- **SON (Self Optimizing Networks)**
  - Coverage and capacity optimization
  - Handover/mobility robustness
  - Automatic load balancing

# LTE Advanced - Spectrum Aggregation

- Often portrayed as “The Panacea” for the use of disparate spectrum blocks
- LTE Advanced will offer aggregation of disparate spectrum within “same band” and blocks in disparate bands but at a significant price
- **Base Station Hardware complexity and cost increases**
  - A separate set of transmitters is needed for each spectrum block driving potential filter, antenna (or combiner) needs, and possible additional feed lines
  - Complexity in system for managing aggregated resources
- **Handset complexity and cost increases**
  - A separate set of receivers is needed for each spectrum block and separate filters/antennas are needed for each band
  - Substantially increased computational requirements
  - Increases cost, complexity, form factor, and power consumption in handset
- **Differences in propagation between different bands could result in varying service levels**

# **CONSIDERATIONS FOR FUTURE SPECTRUM ALLOCATIONS**

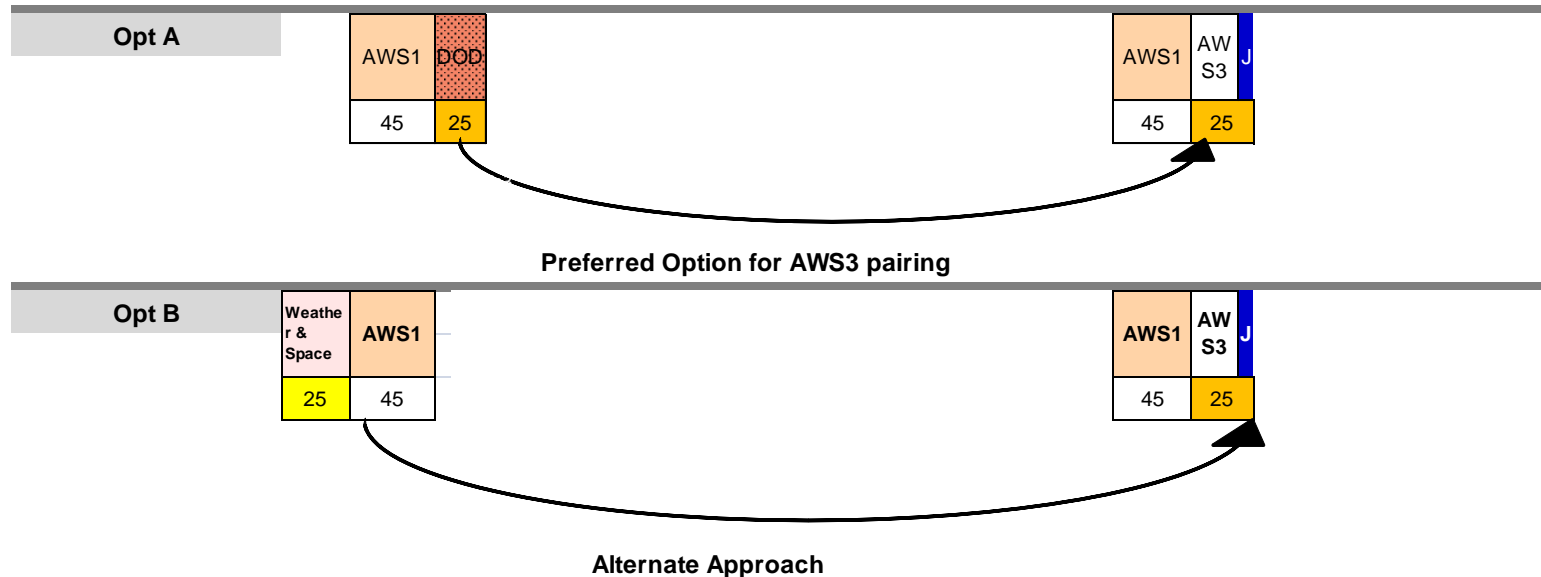
# Carriers' Future Spectrum Needs

- **Contiguous larger spectrum blocks**
  - (10+10, 15+15, 20+20, or more) are needed to allow higher peak data rates and to avoid being forced to use carrier aggregation
- **Worldwide harmonization of bands is essential**
  - Eases international roaming issues (eliminates the need for additional band support in the handset just to support international usage).
  - Minimizes handset cost, complexity, and form factor impacts and allows greater economy of scale for equipment manufacturers driving down overall handset costs
- **Frequencies lower than 3 GHz are desirable**
  - Mobile system operation is most practical below 3 GHz.
  - Bands below 1 GHz can enable economic coverage in rural areas
  - Bands between 1 and 3 GHz allow for larger bandwidths in duplexing equipment and can offer contiguous spectrum in a single channel to deliver their highest spectral efficiency and throughputs
- **Adjacency to existing bands is beneficial**
  - Enables expansion of radio carrier bandwidths by allowing the combination of existing wireless spectrum and reduces handset complexities



# AWS3 Band Pairing

1660	1710	1755	1780	1850	1910	1930	1990	2010	2025	2110	2155	2175	2200	2305	2320	2345	2360						
#5	35	45	25	70	60	55	60	55	10	10	5	85	45	20	10	10	---	15	DARS	15			
Weather & Space	AWS1	DoD			PCS	GH	PCS	GH	TS	IC	J	BAS & Govt		AWS1	AW S3	J	IC	T	S	Govt & Non Govt Satellite	W	C	S



Option A is the industry preferred option as the "AWS3" can be combined with an existing 3GPP IV band; Option B would require a different duplex separation than AWS1 requiring creation of an additional band to support AWS3 as a standalone band. Thus Option A minimizes the number of bands that must be supported in the handset limiting cost and form factor impacts

# UHF Television Band – A Prime Source of New Spectrum

- A voluntary surrender of licenses in an incentive auction is likely to result in a patchwork of blocks being made available across the US. This method of reallocation, by itself, will produce significant technical challenges.
- Pairing for FDD may not be possible forcing TDD operation which will exacerbate co-existence and coordination issues with Broadcast TV.
- 6 MHz block sizes do not match the increments of LTE bandwidths, resulting in spectral inefficiencies.
- It would be a challenge to consolidate multiple adjacent blocks to take full advantage of LTE capabilities offered by wider bandwidths.
- Some channels would be too low in the band for reasonable hardware implementation (becomes problematic for antennas, filters, form factor, and MIMO operation)
- Amount of spectrum available could vary considerably across markets and is likely to be the least in the larger markets where it is most needed

# Implementation Challenges

470	UHF TV Channels																																														860
14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	#	39	40	41	42	43	44	45	46	47	48	49	50	51										
Block 1 Downlink					Block 2 Downlink					Block 3 Downlink					Block 4 Downlink											Block 1 Uplink			Block 2 Uplink			Block 3 Uplink			Block 4 Uplink												
TV					TV					TV					TV													TV				TV	TV			TV											

Note: This is a sample band plan without repacking

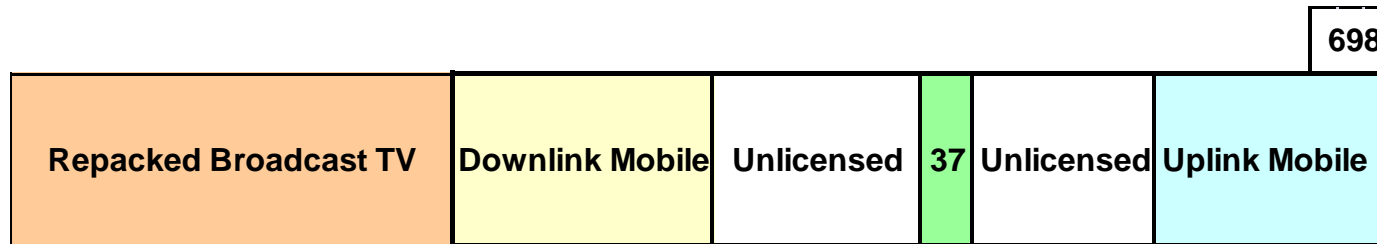
## • Device Implementation Challenges

- A 25-30 MHz duplexer pass band is practical at this frequency range, but a handset designed to operate in the entire UHF TV band would require at least 4-5 duplexers increasing the complexity of the FEM

## • Interference Challenges

- Without repacking of TV transmission channels, mobility operation adjacent to high power television transmitters will be prone to severe interference problems
- Repacking of broadcast channels would make great strides towards allocating 120 MHz of spectrum for mobile broadband use
- Lower UHF channels would provide better propagation for Broadcast TV stations

# Broadcast Band Plan – An Alternative Approach



Disclaimer: Diagram not to scale

- Reallocation should be uniform across the entire US. That is, it should consist of the same set of channels (same block size and frequencies) without any mixing of usage (CMRS amongst BCTV)
- Assigning Channel 37 in the center of the FDD TX/RX duplex separation gap with lower power services on adjacent blocks would allow for maximum protection to radio astronomy
- Repacking of existing broadcasters to lower channels in the UHF band would be needed (and maximizes their range). A reallocated spectrum block needs to begin at the top end of the UHF BCTV band starting with Channel 51
- Reallocation of Ch 51 will resolve part of the Lower 700 MHz Block A interference issue
- Unlicensed bands could include white space and wireless microphone devices

# Conclusions

- **More spectrum is essential**
  - LTE is inherently a more efficient technology but alone is not the panacea to meet the staggering growth in the usage of mobile broadband services
- **Both low and high spectrum bands are beneficial for mobility**
  - Lower frequency bands (below 1 GHz) have propagation benefits and higher frequency band (1-3 GHz) can achieve greater improvements in capacity
- **FCC should consider a holistic band plan**
  - Spectrum should be made available in large contiguous blocks and any reallocated spectrum should be considered as part of a comprehensive spectrum plan
- **Reallocation of TV bands**
  - A defined block of paired contiguous nationwide spectrum is necessary for deployment of mobile broadband services
- **Worldwide harmonization of bands is essential**
  - Eases international roaming issues, minimizes handset cost, complexity, and form factor impacts